

The Virtual City with Real Decisions: ITEAM

Ana Maria de ALMEIDA¹, Moshe BEN-AKIVA², Francisco Câmara PEREIRA¹, Anwar GAUCHE², Cristian Angelo GUEVARA², Samuel NIZA³ and Christopher ZEGRAS²

¹Faculdade de Ciências da Universidade de Coimbra (FCTUC), Universidade de Coimbra, Portugal

²Massachusetts Institute of Technology (MIT), Cambridge, MA, USA

³Instituto Superior Técnico (IST), Universidade Técnica de Lisboa, Portugal

Introduction

The use of city models for supporting simulation-based scenario studies has become a regular practice throughout the world. These models, however, tend to focus on very few aspects (e.g. land-use, transportation) assuming an exogenous participation of other fundamental aspects (e.g. energy, communications). The problem is that a large number of relevant interactions become compromised or even absent at all. And this is even more important with current trends like electrical vehicles or real-time mobility information. For example, for studying future transport systems we need also to include energy supply dynamics.

An important motivation for this apparent simplicity of current models has been that modeling a large number of urban sub-systems, or *integrated modeling*, is not only extremely complex to design but also computationally expensive. While these reasons have justified strong opposition to integrated models in the past (e.g. (Lee, 1973)), the current situation has changed radically, particularly in terms of computational power. More importantly, today we have a much more interconnected city than we had before, with ubiquitous systems, smart-grid, internet, etc. and it's becoming forbidding to ignore such complexity in urban modeling itself.

This paper introduces an integrated transportation and energy activity-based model (iTEAM), a tool for the evaluation of “green policies” aimed at enhancing sustainability and well-being. The model will simulate individual/household and organization/firm agents at a micro level. The aggregate simulation results will help forecast the impacts of policies on transport system efficiency and land-use dynamics in the simulated areas. This process is complemented by Material Flow Accounting (MFA) techniques, which account for a range of factors including well-being, waste production, and carbon emissions to calculate the urban metabolism.

This project is currently implemented at several levels. Data collection consists of a smartphone survey, home-based telemetering, an online survey, acquisition of National Census, and other official population databases. The modeling of individual agents (households, individuals, firms, developers) focuses on activity patterns and is implemented in the *Open Platform for Urban Simulation*, OPUS (Waddell et al, 2003). Work towards the integration of Material Flow Accounting (MFA) (Niza et al., 2009)) in this platform is also progressing.

This paper presents the overall project, with focus on the modeling methodology, coming from Behavioural Econometrics, Transport Engineering and Urban Planning. We present the current status of the project and results reached so far.

Methodological background

Efficient urban management and sustainable development require the critical evaluation of different policies and their impacts. Simulation based approaches, which predict the overall effects of policies by aggregating simulations of individual behavioral responses to policy scenarios, are increasing in popularity (Cowing and McFadden 1984, Altdorfer 2004, Paltsev et al. 2004). An important component of these simulation tools are detailed disaggregate behavioral models that capture the effects of variables affecting energy consumption in different decisions.

Traditional energy micro-simulation focuses on transportation and other residential energy consumption models (Baker, et al, 1989; Nesbakken, 1999; Levinson and Niemannb, 2004; Weber and Perrels, 2000; Cowing and McFadden, 1984), particularly at the level of household choices in vehicles/appliances (including fuel/energy sources) and utilization patterns. However, the real materials and energy consumption behavior is much more complex; and is integrated with urban form and human activity, which are affected by external factors like policy, technology, economy, investments and regulations. For example, transport fuel consumption is strongly influenced by fuel price and factors like land-use patterns, car ownership and vehicle characteristics (e.g. fuel efficiency), day-to-day activity schedules, network conditions like level of congestion, etc. The relationship between these factors and the materials and energy consumption is in fact endogenous since energy consumption decisions also affect these factors in the long run. An unusual increase in gas price for example may affect a range of short and long term decisions. For instance, in the short run there may be an increased propensity to trip chain and use public transport; in the long run, people may eventually choose to live closer to their workplace/city center, purchase more energy efficient/hybrid cars and choose to telecommute.

Capturing these complex two-way conditional and causal interactions calls for an integrated model of urban form, activities and energy usage that departs from micro-simulated agents into aggregated levels that allow for “big picture” perspectives on their impacts. We particularly focus on the Urban Metabolism perspective. The term ‘metabolism’ as applied to a city stems namely from the work of Wolman (1965), Baccini 1991; Brunner et al. 1994; Hendriks et al. 2000, and it refers to the total flow of materials and energy into and out of the urban system (Figure 1 – Overall energy, materials and water flows of Lisbon city (Source: Lisboa E-Nova, 2005, 2006, 2007)).

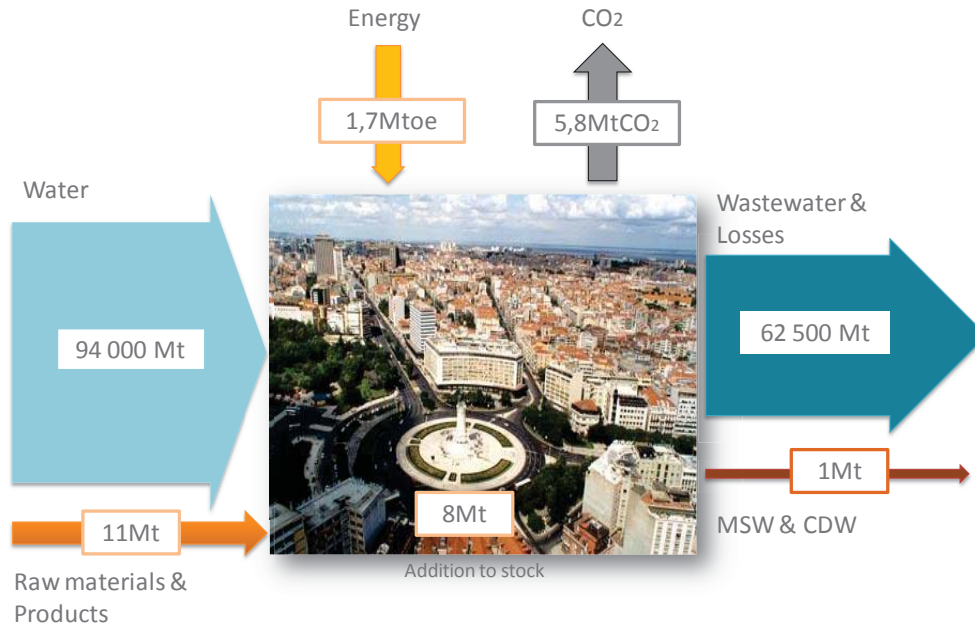


Figure 1 – Overall energy, materials and water flows of Lisbon city (Source: Lisboa E-Nova, 2005, 2006, 2007)

These resource flows are massive and entail significant energy and environmental costs. They also result in the creation of massive additions to the physical stocks of cities; including transportation and other infrastructure networks, buildings, segregated municipal waste streams, household appliances and electronics and many others.

The urban subsystem is dynamic not stationary (Figure 2– Extended metabolism model of human settlements (adapted from Newman, 1999)) so the status of the demand actors and the associated resource flows are constantly changing.

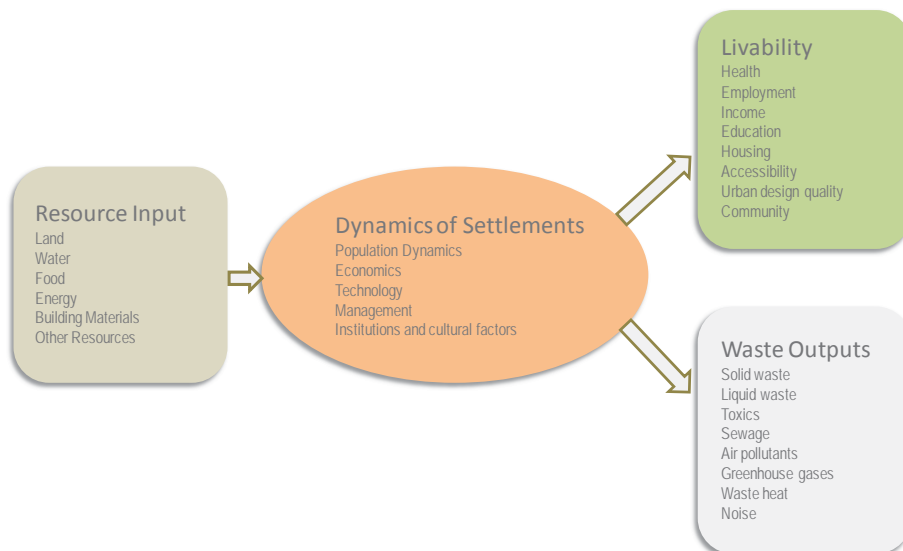


Figure 2– Extended metabolism model of human settlements (adapted from Newman, 1999)

Knowledge about the metabolism of cities allows decision makers to deal with present and prevent future issues regarding material and energy flows and material stocks of a city. Comprehensive information and knowledge is needed on the type and composition of cities' functions, the dynamics of their changes and about how to control and manage them. Thus it is essential to study demand for resources in order to most correctly manage distribution in the frame of a limited natural urban system. The vision of integrated Transportation and Energy Activity-based Model (iTEAM) then consists of the combination of a bottom-up (activity-based microsimulation of agents) with a top-down approach (material flow accounting) in a large-scale model that considers the individual behaviors of all the agents that have direct or indirect impact on transports, energy and land-use of a city as well as on their interactions (Figure 3).

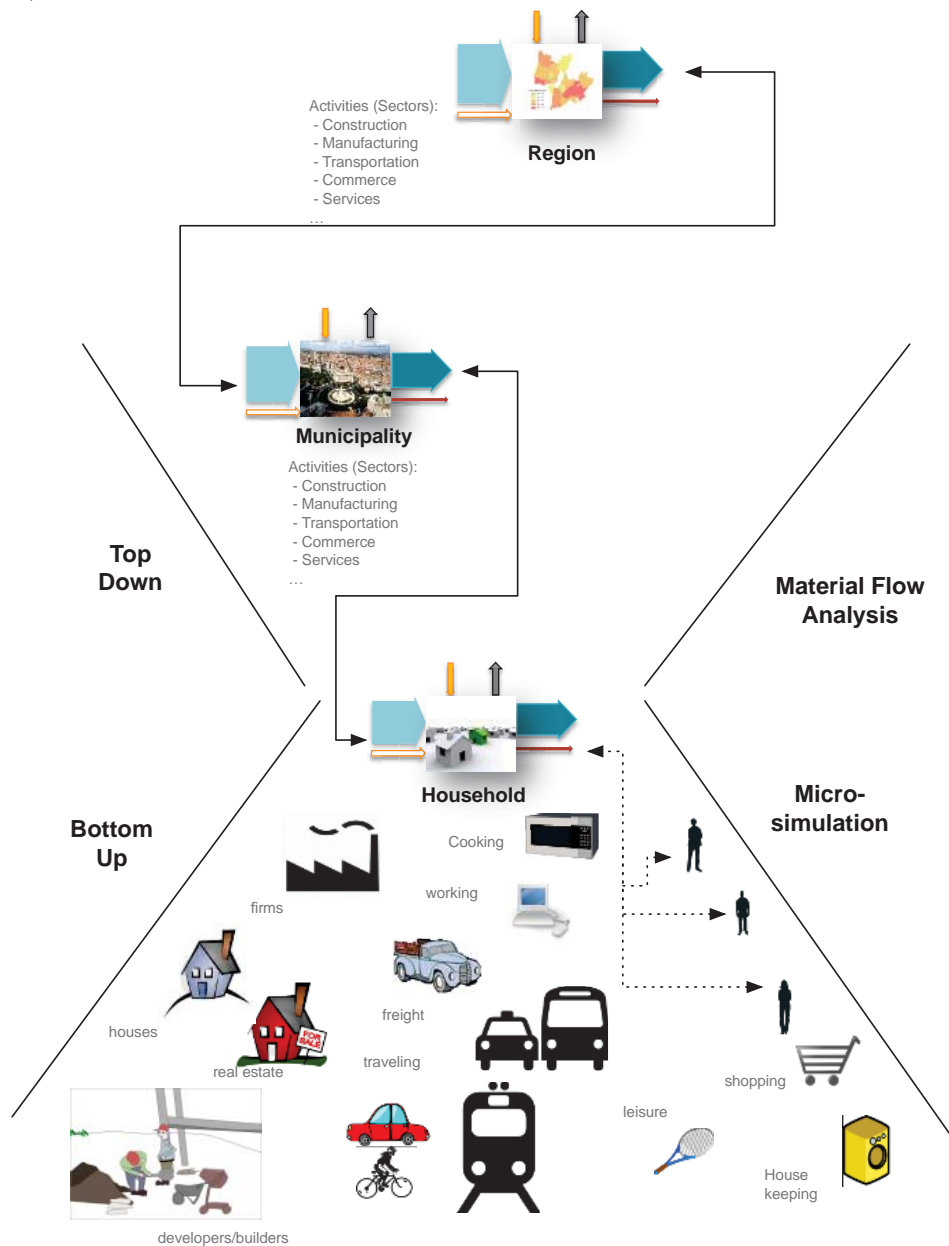


Figure 1 - Top-Down <->Bottom-Up approach

Project architecture

The iTEAM architecture is designed as in figure 4.

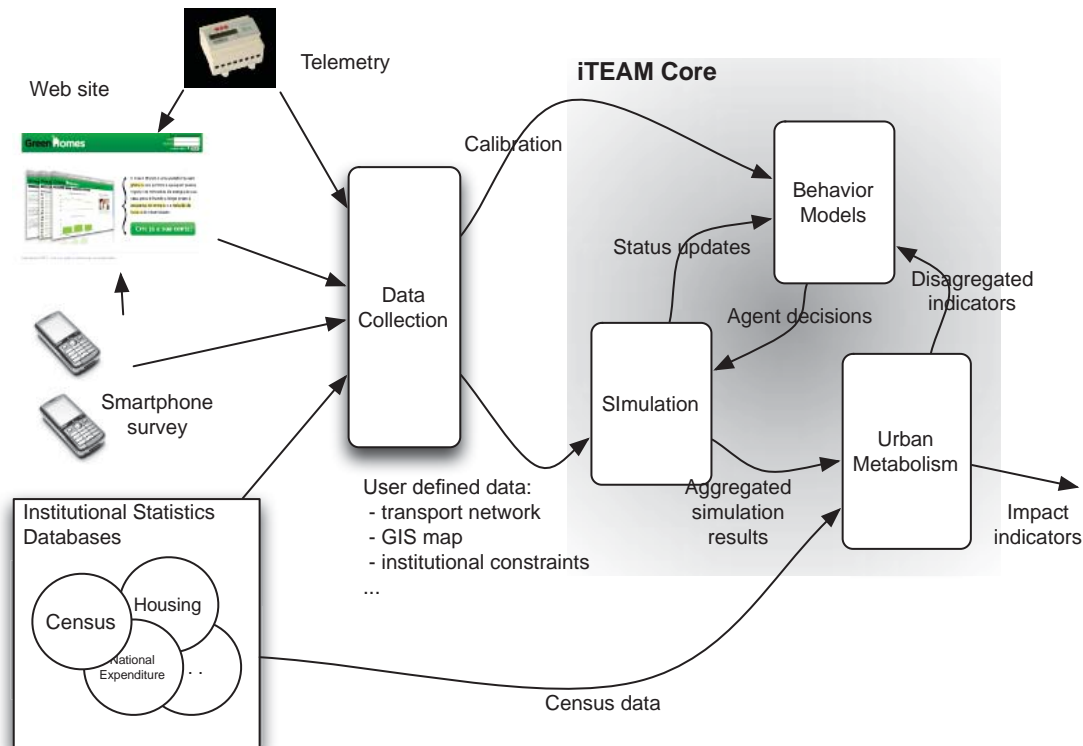


Figure 4 – iTEAM architecture

Initially a number of data collection initiatives are deployed: mobility; in-home behavior; socio-economical profiles; stated preferences; contextual information (e.g. real estate regulations, demographics, etc.). Such information is applied in the calibration of the behavior models that define each agent in the simulation as well as of the Urban Metabolism analysis. Data is also important for other purposes (e.g. road network, population generation). Each agent will behave according to its calibrated model considering the current status of the world and its own pre-defined characteristics. During the simulation, the aggregated results of agent behaviors can then be fed back into the system and at the same time be analyzed by the Urban Metabolism component (which applies MFA to update indicators and disaggregates these into household level). In reality, this interaction of the components of Behavior Models, Simulation and Urban Metabolism (to which we call the iTEAM modeling core) happens inside our simulation platform, based on Open Platform for Urban Simulation, OPUS (Waddell et al, 2003). The architecture is being developed in order to explore the potential benefits from all these.

Current work and immediate plans

There is work in progress in each module. Within the Data Collection module, an online survey is being designed towards individual households that aims to collect information about household socioeconomic characteristics, residence attributes

(price, location, typology, accessibility, insulation), household equipment (major appliances, heating and cooling, subscriptions), mobility and respondent main activities. This survey is to be filled when registering for the online energy monitoring platform, GreenHomes. In this platform, currently entering pilot testing phase, registered users can periodically insert their energy counter values either by hand or automatically with telemetry devices (see figure 5).

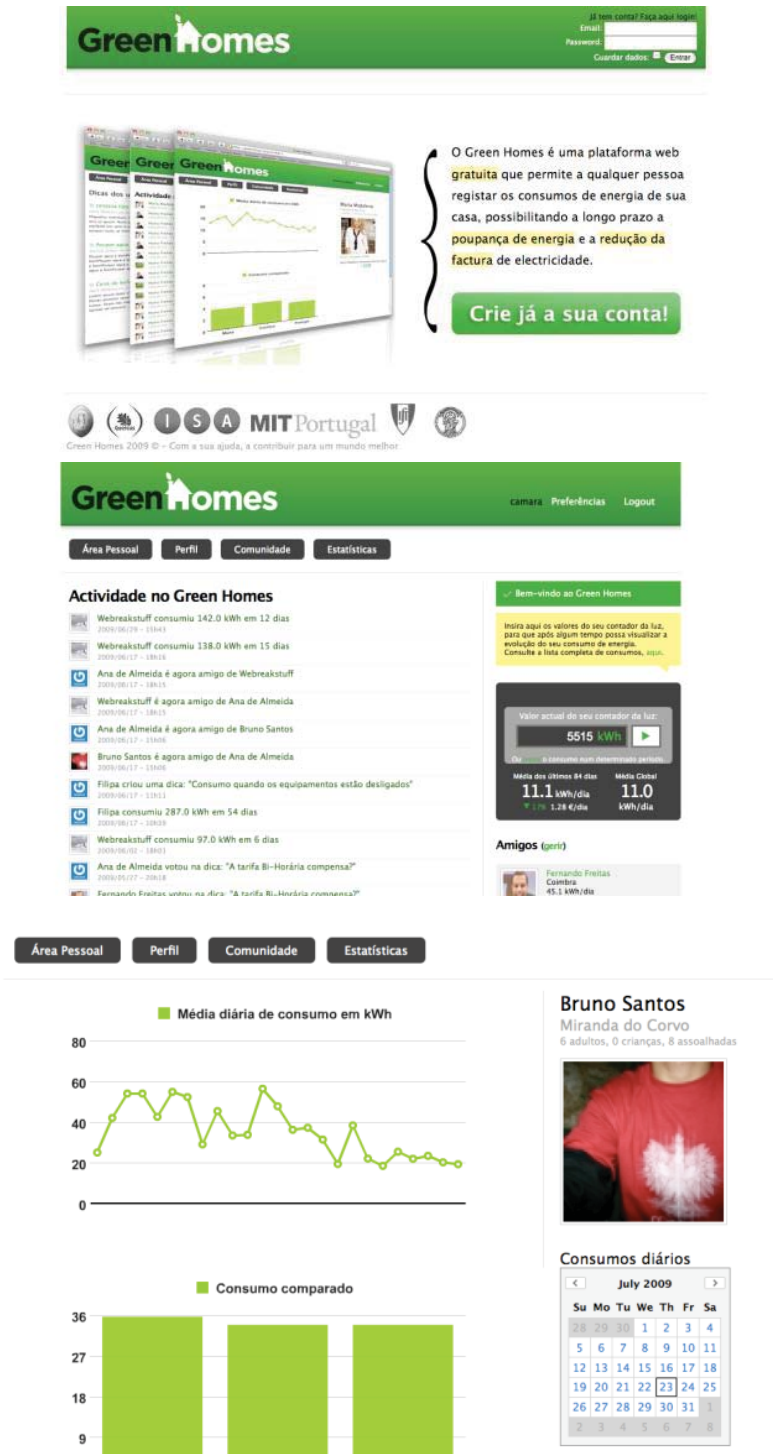


Figure 5 - GreenHomes – Default, data entry and energy consumption monitoring pages

Still on the data collection module, a smartphone survey is being deployed for pilot testing that registers GPS traces and, for each detected stop (when specific spatial temporal constraints are met), asks the user to fill in a few details on which activity is being performed. In reality, this “activity diary” will only be filled when arriving home or in moments of availability from the side of the user.

On the Behavior Models, we are developing various improvements in the household location choice model. The first corresponds to the derivation and assessment of simultaneous estimators to control for endogeneity and the development of statistical tests for the validity of instrumental variables required to perform those corrections. The second modeling drawback to be studied in this sub model corresponds to the development of consistent choice model estimators that will work when only a subset of the full choice set of alternatives is sampled and when the error structure is not identically an independently distributed. These developments will also be extended to the job location model which, in the mid term, will eventually be transformed in a firm location choice model. Finally, an accessibility model is also being designed to evaluate the effects of new smart transport modes and services on household relocation. This will also compensate the absence of an accessibility module that supports user-defined accessibility measures in the current Urbansim package. Regarding the Simulation, a number of extensions are being planned that include the integration of OPUS with an external traffic simulation platform and with a Material Flow Accounting plug-in.

Finally, in the Urban Metabolism module, the MFA analysis for the Lisbon Metropolitan Area is at the moment being developed by using a family expenditure survey as well as other census surveys from INE. As said before, the intention is to automate such analysis in the OPUS platform via a plug-in that exactly follows all the steps of MFA.

The next steps in this project consist of the public deployment of each of the surveys, followed by the results analysis and model calibration. In parallel, input from previous national and regional surveys as well as GIS databases will allow for initial calibration of the model as well as initial experimentation with the baseline OPUS package.

Conclusion

In this paper, we presented our vision and architecture design on the integrated modeling of transports, energy and land-use for the urban context. This is an on-going work effort that has already accomplished its first achievements namely the design of a number of survey technologies. The main contributions expected for the project include the activity-based modeling foundation, the integration of energy, material flow, transports and land-use in the same framework, the application of innovative survey techniques and a number of extensions to the OPUS project.

REFERENCES

- [1] **Cowing T. and McFadden D.** (1984), *Microeconomic Modeling and Policy Analysis Studies in Residential Energy Demand*, Academic Press, Orlando, USA.
- [2] **Lee, D.** (1973). "Requiem for Large Scale Urban Models". *Journal of the American Institute of Planners* 39, 3:163-178.
- [3] **Levinson, A. and A. Niemannb** (2004) "Energy use by apartment tenants when landlords pay for utilities". *Resource and Energy Economics* 26, (1),pp. 51-75
- [4] **Lisboa E-Nova, Agência Municipal de Energia e Ambiente** (2005). *Matriz Energética de Lisboa [Lisbon Energy Balance]*. Lisboa: Lisboa E-Nova.
- [5] **Lisboa E-Nova, Agência Municipal de Energia e Ambiente** (2006). *Matriz Energética de Lisboa [Lisbon Energy Balance]*. Lisboa: Lisboa E-Nova.
- [6] **Lisboa E-Nova, Agência Municipal de Energia e Ambiente** (2007). *Matriz Energética de Lisboa [Lisbon Energy Balance]*. Lisboa: Lisboa E-Nova.
- [7] **Nesbakken, R.** (1999) "Price sensitivity of residential energy consumption in Norway". *Energy Economics* Volume 21, Issue 6, Pages 493-515
- [8] **Newman, P.** (1999). "Sustainability and cities: extending the metabolism model". *Landscape and Urban Planning* 44: 219-226.
- [9] **Niza, S., Rosado, L., Ferrão, P.** (2009). "Urban Metabolism: Methodological Advances in Urban Material Flow Accounting Based on the Lisbon Case Study". *Journal of Industrial Ecology* 13 (3): 384-405.
- [10] **Paltsev S. , L. Viguiet L. , Babiker M. , Reilly J. and Tay K. H.** (2004), "Disaggregating Household Transport in the MIT-EPPA Model", Presented at the 7th Annual Conference on Global Economic Analysis, Washington DC, USA.
- [11] **Waddell, P., A. Borning, M. Noth, N. Freier, M. Becke, G. Ulfarsson.** (2003). "UrbanSim: A Simulation System for Land Use and Transportation". *Networks and Spatial Economics* 3 (43-67).
- [12] **Waddell, P., Borning, A., Noth, M., Freier, N., Becke, M. and Ulfarsson, G.,** (2003) "Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim". *Networks and Spatial Economics*, Vol. 3 No. 1, pages 43-67.
- [13] **Weber, Ch. and A. Perrels** (2000) "Modelling lifestyle effects on energy demand and related emissions" *Energy Policy* 28(8), pp. 549-566